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ABSTRACT

The intent of this document is to provide technical guidance to school district facility managers for linking specific incremental seismic retrofit opportunities to specific maintenance and capital improvement projects. The linkages are based on logical affinities, such as technical fit, location of the work within the building, cost saving opportunities, and scheduling benefits. The key tool to be used to make these linkages is a series of matrices that represent a number of categories of maintenance/capital improvement projects typically undertaken by school districts. Users of the document will typically undertake the following sequence: (1) identify a maintenance/capital improvement project about to be planned or undertaken and go to the applicable matrix or matrices; (2) identify the building types in which the project will be undertaken and note all the applicable seismic retrofit opportunities; (3) review the applicable retrofit measure descriptions provided and incorporate some or all of the applicable measures; and (4) use risk analysis to help in prioritizing a large number of applicable retrofit measures. (Contains 21 line drawings.) (RJM)

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FEMA 318

ED 419 374

Federal Emergency Management Agency

Existing School Buildings

Incremental Seismic Retrofit Opportunities

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July 1995 edition of this manual edited by Len Benning, University of Pittsburgh at Johnstown, Johnstown, Pennsylvania

Preface

In February 1992 the National Science Foundation (NSF) awarded a grant to Building Technology Inc. (BTI) funding a research project titled, *Seismic Mitigation Strategies for Existing School Buildings Which are Subject to Earthquake Risk Throughout the United States*. This document is based on that research. The Co-Principal Investigators were Mr. David B. Hattis, president of BTI, and Dr. Frederick Krimgold of the Virginia Polytechnic Institute and State University. The principal author of this document was Mr. Melvyn Green, P.E., president of Melvyn Green and Associates, project consultant. BTI would like to acknowledge the American Association of School Administrators (AASA) and the Council of the Great City Schools for the services and support provided by them.

Participants in the research included the following school districts:

- Blytheville Public Schools (Blytheville, Arkansas)
- School Administrative Unit #8 (Concord, New Hampshire)
- School Administrative Unit #21 (Hampton, New Hampshire)
- Memphis City Schools (Memphis, Tennessee)
- Board of Education of the City of New York (New York, New York)
- Ogden City Schools (Ogden, Utah)
- Portland Public Schools (Portland, Oregon)
- Seattle Public Schools (Seattle, Washington)

On November 11 and 12, 1993 a review panel met to discuss the preliminary findings of the research and advise the BTI team on the development of the information presented herein. Participants in this meeting included representatives from the following school districts and organizations:

- Blytheville Public Schools - Blytheville, Arkansas
- Central Kitsap School District 401 - Silverdale, Washington
- The Council of Educational Facility Planners International
- Division of Risk Management - State of Utah
- Fairbanks - North Star School District - Fairbanks, Alaska
- Federal Emergency Management Agency
- Iron County Schools - Cedar City, Utah
- Memphis City Schools - Memphis, Tennessee
- New York City Board of Education - New York, New York
- Ogden City Schools - Ogden, Utah
- Portland Public Schools - Portland, Oregon
- St. Louis Public Schools - St. Louis, Missouri
- Seattle Public Schools - Seattle, Washington
- School District # 25 - Pocatello, Idaho
- Tucson Unified School District - Tucson, Arizona

Under Federal Emergency Management Agency (FEMA) Contract #EMW-91-C-3636, *Technology Transfer on Seismic Rehabilitation of Existing Buildings*, awarded September 1991, BTI with the assistance of Mr. Green and Dr. Krimgold has enhanced this document for use in workshops and other presentations. Under this contract BTI is responsible for the promotion and conduct of general audience and targeted audience workshops, the development of materials (including lectures, slides, videos, and publications) in support of these workshops, the preparation and delivery of presentations under a speakers bureau, and the distribution of the entire series of FEMA publications regarding the subject of seismic mitigation of existing buildings.

BTI gratefully acknowledges the valuable assistance and cooperation provided by Mr. William A. Anderson, Ph.D., Head, Hazard Mitigation Section, National Science Foundation and Ms. Marilyn MacCabe, Project Officer, Federal Emergency Management Agency..

DISCLAIMER - Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or Federal Emergency Management Agency.

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I. Introduction

Intent of This Document and Use of the Matrices

The intent of this document is to provide technical guidance to school district facility managers for linking specific incremental seismic retrofit opportunities to specific maintenance and capital improvement projects. The linkages are based on logical affinities including technical fit, location of the work within the building, cost saving opportunities and scheduling benefits.

The key tool to be used to make these linkages is the series of matrices in Chapter IV. There are a number of categories of maintenance/capital improvement projects typically undertaken by school districts. For the purposes of this document there is one matrix for each of five categories of maintenance/capital improvement projects. The rationale for grouping the work into these five categories is discussed in Chapter II.

The horizontal axis of each matrix consists of different building types, which are discussed in Chapter III. The vertical axis of each matrix consists of discrete seismic retrofit measures. The potential linking of retrofit measures with maintenance/capital improvement projects is displayed by designations in the matrix intercepts (Chapter IV). If specialized engineering analysis is needed to implement a given retrofit measure, this is designated in the matrix as well. The retrofit measures and the rationale for the linkages are specified in more detail in Chapter V.

A user of this document will typically undertake the following sequence:

- Identify a maintenance/capital improvement project about to be planned or undertaken and go to the applicable matrix or matrices, either directly or on the basis of a review of Chapter II.
- Identify the building type(s) in which the project will be undertaken, and moving down the applicable matrix column(s), note all the applicable seismic retrofit opportunities.
- Review the applicable retrofit measure descriptions in Chapter V, and based on the budget, incorporate some or all of the applicable measures into the project plan.
- Risk analysis may assist in the prioritization of a large number of applicable retrofit measures, and guide the selection of those to be implemented.

Relationship of This Document to *Existing Buildings -- Facilities Management Models*

The *Existing Buildings -- Facilities Management Models* is a related document to be used by school districts. It describes the activities typically undertaken by school districts in the management of their existing buildings, and it presents two extreme approaches:

- Model A -- Facilities Management with Reactive Facilities Planning
- Model B -- Facilities Management with Proactive Facilities Planning

Most school districts will be able to relate their facilities management activities to one of these models, or to some combination of both.

School districts which generally follow Model A are encouraged to use the information and the approach contained herein during the implementation phase of maintenance and capital improvement projects. It is anticipated that the steps outlined above will be applicable.

School districts which generally follow Model B are encouraged to undertake seismic screening and evaluation of their buildings long before the implementation of maintenance and capital improvement projects. These activities will precede the steps outlined above, and will provide the facility managers with an understanding of the seismic risks in their buildings. This document will serve as a planning tool which, in combination with seismic risk analysis, will help the facility managers identify cost effective incremental seismic retrofit measures for implementation.

II. Maintenance and Capital Improvement Activities

Terms

Terms used herein are considered typical of those used by school facility managers.

Work Categories

The eight categories of maintenance and capital improvement projects included in this chapter are often used by school facility managers to categorize their programs. They reflect categories of building elements, administrative and funding categories, or other parameters. Some school districts may use other categorizations of maintenance and capital improvement work. The purpose of this discussion is not to impose any particular categorization of work, but simply to lead facility managers from a particular item of work being planned into the matrices, so that they may consider adding particular incremental retrofit measures to the work. Thus, users of this document are encouraged to modify the work categories for their own convenience.

Additions

Additions have been constructed on many schools over the course of their useful lives. Current additions will be designed to meet the seismic requirements of the building code. Additions may also offer opportunities to strengthen an adjacent building or buildings. These opportunities require careful design and analysis, and they are not specifically identified in the matrices. Furthermore, inadequately designed additions, without proper joints or connections to the existing building, could actually weaken the buildings.

A. ROOFING MAINTENANCE AND REPAIR / REROOFING

General Description of the Work

This category of work is possibly the most common work in buildings. It includes repair or replacement of any or all of the following elements:

- Roof drainage system
- Eaves and facias
- Flashing
- Vents
- Roofing membrane
- Insulation
- Walking surface/ballast
- Parapets/caps
- Roof-mounted equipment
- Roof deck
- Other

Most roof maintenance and repair work is done either in response to a failure, or as scheduled periodic maintenance or preventive maintenance work. Most seismic retrofit opportunities will relate to either scheduled or preventive maintenance. Placement of roof-mounted equipment usually relates to other work categories such as modernization.

Physical Description of the Work

Work on the roof can be localized to specific areas, can extend to the entire perimeter of the roof, or may involve the complete roof surface or large portions of it. Work may be limited to the roofing membrane or may include work on the substrate, deck, and supporting system.

Factors Impacting the Work

Roof work is usually the result of problems or scheduling.

Performance of the Work

Repair work on the roof is often performed by district maintenance staff. Outside contractors may be used for more extensive work.

An architecture/engineering (A/E) firm is typically used in relation to the installation of mechanical, electrical, telecommunication or similar equipment. Also, districts often use the services of an A/E for preparation of reroofing specifications and bid documents.

Special Equipment

Scaffolding is sometimes used in connection with roof work. Cranes or hoist may be used to lift materials or equipment.

Impact of Work on Building Use

Work on the roof generally does not interrupt building use, except for complete reroofing including the deck.

B. EXTERIOR WALLS MAINTENANCE AND REPAIR / WINDOW REPLACEMENT

General Description of the Work

Exterior wall maintenance and repair may involve the following activities:

- Pointing
- Patching
- Painting
- Caulking

This item may also include major projects such as:

- Window repair and replacement
- Refinishing with new cladding or material

Most exterior wall maintenance and repair work is done in response to failure or as scheduled periodic maintenance or preventive maintenance work. Caulking and window repair and replacement are also often linked to energy conservation/weatherization work.

Most seismic retrofit opportunities will relate to scheduled and preventive maintenance and weatherization work.

Physical Description of the Work

Work is usually carried out through an entire school as a scheduled maintenance activity, although localized patching work is possible. Work may include: repointing of brick exterior walls, window replacement, and energy conservation improvements.

Factors Impacting the Work

Federal or state mandates which require energy conservation improvements may lead to window repair or replacement.

Performance of the Work

Exterior wall and window work may be performed by skilled construction personnel on the district staff or by an outside contractor.

In many cases there may be an A/E involved to provide design, specifications, bid process and construction administration services.

Special Equipment

Specialized equipment will often be necessary to reach higher exterior areas. This may include scaffolding or swing stages. This access may provide economical opportunities for the integration of seismic retrofit measures.

Impact on Building Use

Since most of the work is being performed from the building exterior it may be possible to accomplish it throughout the school year. However, some of the seismic retrofit measures may be noisy or require access from the interior, so this work may have to be done when the building is vacant.

C. FIRE AND LIFE SAFETY IMPROVEMENTS

General Description of the Work

Fire and life safety improvements may involve the following building elements:

- Corridors/Doors
- Stairs
- Lobbies
- Entrances
- Alarms, standpipes and automatic fire sprinkler systems

Districts will usually schedule this work as part of the planning process. Only if the work is in response to a disaster, such as a fire, will the work be unplanned. However, a building disaster which requires some construction may provide an opportunity to integrate seismic safety improvements.

Physical Description of the Work

Fire and life safety improvements usually involve the building's means of egress, which will effect specific internal spaces. Often the work is near the center of the building -- the corridors. It may in some cases affect exterior walls -- lobbies and entrances. Items include:

- The removal and replacement of corridor wall finishes, doors, transoms and equipment (e.g., lockers and cabinets) will provide access to walls and ceilings.
- Fire separations and stairway enclosures may involve installation of new walls or alteration to existing walls, either of which may be designed as shear walls.
- New stairways may be installed either within the building or on the exterior. If stairways are added, the work may require removal of part of a floor and the construction of new walls providing the opportunities for new shear wall construction.
- Installation of alarms, standpipes or sprinklers may provide access for the installation of anchor bolts or shear wall extensions from the ceiling to the roof.

Any new or altered wall provides a seismic safety improvement opportunity.

Factors Impacting the Work

This category of work is usually mandated rather than routine. It may be in response to a building or fire code requirement, or as part of the long range safety improvement plan of the district. It may also be part of a general modernization which provides the opportunity to implement this work category.

Performance of the Work

Typically this work involves skilled construction personnel. These may be district personnel or contractors. In some cases an A/E is involved.

Special Equipment

No special equipment is required for this task except for scaffolding to provide access to the work areas.

Impact on Building Use

Typically this work will be performed when the building is vacant.

D. MODERNIZATION / REMODELING / NEW TECHNOLOGY

General Description of the Work

Facility modernization and remodeling work has the potential to involve any interior or exterior wall or element. This category may involve simple work on a single wall or the entire space reconfiguration of the building. The following are some of the elements that may be affected:

- Walls and partitions
- Ceilings
- Floors
- Concealed areas
- New technology in education requirements

Interior remodeling and modernization are usually major activities and are included in the long range educational plans of the district. Thus, it is a common capital improvement activity.

Physical Description of the Work

This work may include removal of walls and ceilings, construction of new partitions and installation of replacement finishes. This access to spaces behind finishes and the new wall construction provide various opportunities for seismic retrofit work.

Performance of the Work

This work will usually be performed by skilled construction personnel, either district staff or contractor personnel.

Usually architectural/engineering design is used for major remodeling.

Special equipment required for access to work areas for any seismic retrofit construction will typically be available during any remodeling work.

Outside Factors Impacting the Work

Frequently this work is in response to changing educational requirements. It may also be triggered by federal or state mandates.

Impact on Building Use

Major remodeling will require the space to be vacated during the course of construction.

E. UNDERFLOOR AND BASEMENT MAINTENANCE AND REPAIR

General Description of the Work

Underfloor and basement maintenance may involve the following activities:

- Repair of deterioration
- Termite repair
- Equipment replacement

Most underfloor repair activities will be in response to a problem. The solution may be immediate or assigned to the capital improvements budget. For example, settlement and resulting underpinning repair may be the result of a floor problem and require major intervention.

Physical Description of the Work

Work includes replacement of deteriorated wood elements, repair of cracked or bowed walls, underpinning where buildings have settled, replacement of basement equipment and similar activities.

When this work is being planned, seismic retrofit measures that can integrate into this should be considered.

Factors Impacting the Work

Usually there are no mandates or code issues involved with underfloor repair work. Safety is the usual driving force.

Performance of the Work

The work is often performed by school district staff or by outside contractors.

Special Equipment

Special equipment is usually required for underfloor work. However access is usually all that is necessary. Major design work will often require A/E services.

Impact on Building Use

The work may be done at any time, independent of building use.

F. ENERGY CONSERVATION / WEATHERIZATION/AIR-CONDITIONING

The retrofit measures applicable to this category are derived from the Roofing, Exterior Walls and/or Modernization/Remodeling Matrices. Please refer to one or more of these matrices after review of the information below.

General Description of the Work

Energy conservation/weatherization and air-conditioning alterations may affect:

- Exterior envelope work
- Insulation
- Windows
- Building equipment
- Ducts and piping

Elements affected may include:

- Exterior walls
- Ceilings and attic space

Energy conservation improvements and the addition of air conditioning may be in response to a long term school district policy, special state or federal funding, or as part of other routine equipment replacement. In all cases the intent is not only to save energy but also to reduce operating costs.

Energy conservation improvements typically involve the following:

- Window alteration or replacement
- Addition of insulation in the attic or on the roof deck
- Installation of new, energy efficient HVAC equipment.

These lead to a number of seismic retrofit opportunities.

Physical Description of the Work

The physical work involved in energy conservation improvements may be localized or involve the entire building. Items include:

- Window improvements or replacement which may permit the installation of anchors or retrofit of exterior walls.
- New insulation in the attic which may permit access to the ceiling space where anchor bolts could be installed to the roof.

- Insulation installed on the roof deck which eases the installation of parapet bracing, wall anchors and new plywood diaphragms.
- Equipment installation should meet the anchorage requirements for seismic forces and may provide access to areas for anchor bolt installation.

The addition of air-conditioning may include the installation of ducts or piping to all spaces which in turn may lead to consideration of some of the retrofit measures related to remodeling/modernization activities.

Factors Impacting the Work

Federal or state mandates may be factors leading to energy conservation improvements. If special grants are available they can be made part of a program. Local building code requirements may also encourage energy conservation improvements.

Performance of the Work

The work may be performed by school district personnel or by outside contractors depending on the project size or complexity. Whether the services of an A/E are required will depend on the nature of the work.

Special Equipment

Special equipment may be required to provide access to the work. This may include scaffolding or a crane or lift.

Impact on Building Use

Some of this work may be done at any time of year from the roof. Most window or interior work must be accomplished when school is not in session. Typically this work cannot be done around occupants and may require the building to be vacant.

G. HAZARDOUS MATERIALS ABATEMENT

This is a frequent school maintenance or capital improvement category. The retrofit measures applicable to this category are derived from the Modernization/Remodeling Matrix. After review of the information below, please refer to this matrix for applicable retrofit measures.

General Description of the Work

Abatement of hazardous materials may involve work such as the following:

- Asbestos abatement
- Lead paint abatement
- Radon abatement

Most districts have had asbestos abatement programs for some time and radon programs more recently. Lead paint has been recognized as a hazard for some time, but only recently has it been included in government programs for abatement. At this time the methodologies and requirements related to lead paint abatement are in the formative stage.

Physical Description of the Work

Hazardous materials abatement may include the removal of finishes such as plaster, ceiling materials and flooring. It may include removal of the adhesives used. Asbestos abatement may include the removal or encapsulation of insulation on pipes and ducts. Lead paint abatement may include removal of the paint and finishes or encapsulation of the assembly. Radon abatement may require installation of ventilation systems or work in the basement.

In some cases the extent of the work may provide access to interior spaces that will provide a seismic retrofit opportunity. Seismic retrofit work could follow the hazard mitigation work before the finishes are reinstalled.

Factors Impacting the Work

Hazardous materials abatement programs may be triggered by federal requirements or mandates, state regulations or school district policies.

Performance of the Work

The work is typically performed by specialty contractors or specially trained school district staff.

Special Equipment

Special equipment such as scaffolding would often be on the job as part of the abatement work. Other special equipment such as fans and enclosures are irrelevant to seismic work.

Impact on Building Use

Building use will be curtailed during any hazardous materials abatement work. The work cannot be done around occupants. It requires a vacant building.

H. ACCESSIBILITY IMPROVEMENTS

General Description of the Work

Accessibility improvements usually do not lead to seismic retrofit opportunities. Interior work relating to corridors and circulation routes may share some seismic retrofit opportunities with fire and life safety improvements (see Fire and Life Safety Matrix). Other interior work may lead to localized seismic retrofit opportunities but no major mitigation.

Installation of an elevator may provide an opportunity to use the new shaft walls as shear walls.

Physical Description of the Work

Most work involves revisions to walks and doors. Ramps are constructed and in some cases elevators or lifts installed.

Toilet room improvements may require the removal of finishes and possibly construction of new walls.

Factors Impacting the Work

Typically such work is done in response to a complaint, or a federal or state mandate. It is often included as part of the long range plans of the district.

Performance of the Work

Accessibility improvements may be accomplished by school district staff or by outside contractors. Often the services of an A/E are utilized.

Special Equipment

No special equipment is used in this work that might be of assistance in seismic retrofit. However, any scaffolding used for interior finish work can provide access for seismic retrofit.

Impact on Building Use

Usually this work can be done around occupants of the building. It does not require a vacant building.

III. Building Types

Building types included herein are an aggregation of the types described in the two FEMA Handbooks, *FEMA 154 - Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* and *FEMA 178 - NEHRP Handbook for the Seismic Evaluation of Existing Buildings*. The respective FEMA designations are noted at the start of each building type description. The building types were selected because they are considered to be the most common types of construction used for schools. Therefore they can be easily used by school facility managers for the purposes of this document. Comments and clarification have been added to some of the types. Furthermore, it is recognized that there will be school structures of other building types, and those not described below can be found in the two FEMA Handbooks.

Most school buildings prior to World War II are of similar construction, masonry walls that are bearing or infill with concrete frame construction.

A. Wood Frame

- FEMA 154 (Screening) -- Type W
- FEMA 178 (Evaluation) -- Types 1 and 2

Frame school buildings usually have dividing walls at regular intervals based on classroom size. The building types included in the two FEMA Handbooks do not readily fit school structures.

Wood frame school buildings are typically single story structures. The essential structural character of this type is repetitive framing by wood joists on wood stud walls. Loads are relatively light but the spans may be relatively long. There may be beams and columns to support the roof or floor. Roofs may be truss supported. These buildings may have relatively heavy chimneys and may be partially or fully covered with veneer.

Many smaller school buildings are not engineered; however, they usually have the components of a lateral-force-resisting system, even though it may be incomplete. Lateral loads are transferred by diaphragms to shear walls. The diaphragms are roof panels and floors. Shear walls are exterior walls sheathed with plank siding, stucco, or plywood. Interior partitions are sheathed with plaster or gypsum board.

B. Unreinforced Masonry Bearing Wall Buildings

- FEMA 154 (Screening) -- Type URM
- FEMA 178 (Evaluation) -- Type 15

Many schools are constructed of unreinforced masonry (URM). They may be from one to three or more stories in height. These buildings include structural elements that vary depending on the age of the building and, to a lesser extent, the geographic location of the structure: In buildings built before 1900, the majority of floor and roof construction consists of board sheathing

supported by wood subframing. In large multistory buildings built after 1900, the floors may be cast-in-place concrete supported by the unreinforced masonry walls and/or steel or concrete interior framing.

Unreinforced masonry buildings built after 1950 with wood floors usually have plywood rather than board sheathing. More recently, in regions of lower seismicity, unreinforced masonry buildings can include floor and roof framing that consists of metal deck and concrete fill supported by steel framing elements. The perimeter walls, and possibly some interior walls, are unreinforced masonry. The walls may or may not be anchored to the diaphragms. Ties between the walls and diaphragms are more common for the bearing walls than for walls that are parallel to the floor framing. Roof ties usually are less common and more erratically spaced than those at the floor levels. Some structures may have pre-cast concrete horizontal elements with or without cast-in-place topping.

Interior partitions that interconnect the floors and roof can have the effect of reducing diaphragm displacements.

URM construction has been a major cause of death and injury in past earthquakes and is considered one of the high risk building types. Most seismic rehabilitation activity to date has been directed at this type of construction.

C. Reinforced Masonry Wall Buildings

Reinforced Masonry Bearing Walls With Wood/Metal Deck Diaphragms

- FEMA 154 (Screening) -- Type RM
- FEMA 178 (Evaluation) -- Type 13

These buildings have perimeter bearing walls of reinforced brick or concrete-block masonry. The walls are the vertical elements in the lateral-force-resisting system. The floors and roofs are framed in one of the following ways:

- wood joists and beams with plywood or sheathing (straight or diagonal), or
- steel beams with metal deck (with or without a concrete fill).

Wood floor framing is supported by interior wood posts or steel columns; steel beams are supported by steel columns. This type of building, if properly engineered, has performed well in past earthquakes.

Reinforced Masonry Bearing Walls With Precast Concrete Diaphragms

- FEMA 154 (Screening) -- Type RM
- FEMA 178 (Evaluation) -- Type 14

These buildings, typically built after 1950, have bearing walls similar to those buildings described in the preceding paragraph, but the roof and floors are composed of precast concrete elements such as planks or tee-beams and the precast roof and floor elements are

supported on interior beams and columns of steel or concrete (cast-in-place or precast). The precast horizontal elements often have a cast-in-place topping. This type of building may pose hazards when the elements are not connected together adequately or there is an inadequate diaphragm.

D. Steel Frame Buildings

Steel Frame With Infill Masonry Shear Walls

- FEMA 154 (Screening) -- Type S5
- FEMA 178 (Evaluation) -- Type 7

This is one of the older types of building. It consists of a steel frame with brick or other masonry bearing on the individual story beams. The hazard posed by this building type is the risk of the walls failing or shearing and collapsing either outward or inward.

There has been much recent research on this infill type of construction. Analysis methods are being developed for use by engineers.

Steel Moment Frame

- FEMA 154 (Screening) -- Type S1 MRF
- FEMA 178 (Evaluation) -- Type 3

These buildings have a frame of steel columns and beams. In some cases, the beam-column connections have very small moment resisting capacity but, in other cases, some of the beams and columns are fully developed as moment frames to resist lateral forces. Usually the structure is concealed on the outside by exterior walls, which can be of almost any material (curtain walls, glazing, brick or other masonry, or precast concrete panels), and on the inside by ceilings and columns furring. Lateral loads are transferred by diaphragms to moment resisting frames. The diaphragms can be of almost any material. The frames develop their stiffness by full or partial moment connections. The frames can be located almost anywhere in the building. Usually the columns have their strong directions oriented so that some columns act primarily in one direction while the others act in the other direction, and the frames consist of lines of strong columns and their intervening beams. Steel moment frame buildings are typically more flexible than shear wall buildings. This low stiffness can result in large interstory drifts that may lead to extensive nonstructural damage.

After World War II there were numerous experiments with different construction materials. Low rise and one story steel frames were frequently used for school construction.

Steel Braced Frame

- FEMA 154 (Screening) -- Type S2
- FEMA 178 (Evaluation) -- Type 4

These buildings are similar to moment frame buildings except that the vertical components of the lateral-force-resisting system are braced frames rather than moment frames.

E. Concrete Buildings

Concrete Frame With Infill Shear Walls

- FEMA 154 (Screening) -- Type C3
- FEMA 178 (Evaluation) -- Type 10

Many schools have been constructed with concrete frames and infill masonry walls. They may range from one to several stories. Because the assumption was that the weight resolved the wind forces, these buildings have often not been designed for lateral loads, either wind or seismic. These buildings are similar to the steel infill structures described above except that the frame is of reinforced concrete. A special hazard of these buildings is the "short column" condition where the masonry wall prevents the column from bending, causing it to shear and leading to potential collapse.

This type of building construction is considered a high potential risk.

Precast/tilt-up Concrete Walls With Lightweight Flexible Diaphragm

- FEMA 154 (Screening) -- Type PC1
- FEMA 178 (Evaluation) -- Type 11

These buildings have a wood or metal deck roof diaphragm, often very large, that distributes lateral forces to precast concrete shear walls. The walls are thin but relatively heavy while the roofs are relatively light. Older buildings often have inadequate connections for anchorage of the walls to the roof for out-of-plane forces, and the panel connections often are brittle.

While usually used in warehouses or light industrial construction, this type of construction could be used in gymnasiums, cafeterias, auditoriums or multi-purpose rooms.

Concrete Moment Frame

- FEMA 154 (Screening) -- Type C1
- FEMA 178 (Evaluation) -- Type 8

These buildings are similar to steel frame buildings except that the frames are of concrete. There is a large variety of frame systems. Buildings in zones of low seismicity

or older buildings in zones of high seismicity can have frame beams with broad shallow cross sections or are simply the column strips of flat-slabs. Modern frames in zones of high seismicity are detailed for ductile behavior and the beams and columns have definitely regulated proportions. This type of building may be a high risk structure in some seismic zones.

Relationship of Building Types

Retrofit Opportunities Matrices	Wood Frame	Unreinforced Masonry	Reinforced Masonry	Steel					Concrete					
Rapid Visual Screening FEMA 154	W	URM	RM	S-1 -MOMENT RESISTING STEEL FRAME	S-2 - BRACED STEEL FRAME	S-3 - STEEL-LIGHT METAL	S-4 - STEEL FRAME W/ CONCRETE SHEAR WALL	S-5 - STEEL FRAME W/ URM INFILL SHEAR WALL	C-1 CONCRETE MOMENT RESISTING FRAME	C-2 - CONC SHEAR WALL BLDG	C-3 - CONC FRAME URM INFILL	PC-1 - TILT UP W/ LT. WEIGHT DIAPHRAGM	PC-2 - PRECAST CONCRETE FRAME	
Evaluation Handbook Types - FEMA 178	1 - (W-LF)	15 -(URM)	13 - (RM-LT DIAPH)	3 - (MOMENT RESISTING STEEL FRAME)	4 - (BRACED STEEL FRAME)	5 - (STEEL-LIGHT METAL)	6 - (STEEL FRAME W/ CONCRETE SHEAR WALL)	7 - (STEEL FRAME W/ URM INFILL SHEAR WALL)	8 - (CONCRETE MOMENT RESISTING FRAME)	9 - (C-2 - CONCRETE SHEAR WALL BUILDING)	10 - (C-3 - CONCRETE FRAME W/ URM INFILL)	11 - (CONCRETE TILT UP W/ LT. WEIGHT DIAPHRAGM)	12 - (PC-2 - PRECAST CONCRETE FRAME)	
	2 - (W - C&I)		14 - (RM PC DIAPH)											

IV. The Matrices: Retrofit Measures and How To Use Them

Overview and Intent

Each of the following matrices represents a category of maintenance or capital improvement activities which may serve as a "trigger" for seismic retrofit measures. These activities were discussed in Section II. Along the left of each matrix is a series of retrofit measures. These measures are the seismic risk reduction efforts that may be possible and more efficiently accomplished when the "trigger" activity is being planned and constructed. Each retrofit measure is numbered and discussed in greater detail in Chapter V of this document.

Along the right side of the matrix is a column entitled "Applicability." This indicates if a measure is recommended in all seismic zones or only in the higher seismic zones (UBC 2B, 3 & 4; NEHRP $A_v \geq 0.20$).

Terminology

Specific terms used in the matrices include the following:

Applicability - Some retrofit measures are necessary in every seismic zone, others only in the higher seismic zones. This section suggests the appropriate seismic zones for the specific measure.

Maintenance Activities - (Triggers) These are the maintenance and capital improvements that school facilities personnel would typically undertake. The various maintenance activities are discussed in Section II.

Retrofit Measures - These are the potential measures that may be "dovetailed" with maintenance or capital improvement activities. Each retrofit measure should be carefully considered in the context of the planned maintenance work item. In some cases it may be easy to accomplish seismic hazards reduction; in others there may be considerable additional work required.

■ This indicates that this retrofit measure is typically necessary on the specific building construction type.

❑ This indicates that the retrofit measure may be necessary on the specific building under the following conditions:

- Condition exists in the building itself
- Based on an evaluation of the building using *FEMA 178 - NEHRP Seismic Evaluation Handbook*

* **Engineering Design** - Each measure that may require engineering design is noted. While many measures can be installed as shown, engineering design may often lead to less cost. A number of measures cannot be done without professional design.

An example of the former is parapet brace spacing. The spacing is a function of seismic zone and parapet height. The most cost effective spacing can only be determined by design. While the arbitrary spacing will usually be safe, it may possibly result in an "overbuilt" condition.

Two examples of the latter are shear transfer and shear capacity. In the case of shear transfer improvements, engineering design is mandatory to ensure that the detailing and spacing are appropriate. In the case of shear capacity, where different materials are added in a line of existing materials, such as a steel brace added to a masonry wall, a stiffness compatibility analysis must be made. Thus engineering design may be quite rigorous.

A. Roofing Maintenance and Repair/Re-roofing

Roofing Replacement and Repair
Parapet Repointing
Flashing Repair/Rework
Air Conditioning Installation

Measure No.	Retrofit Measure	Building Type: Wood Frame	Unreinforced Masonry	Reinforced Masonry	Steel Frame	Concrete Frame	Applicability
1	Parapet Bracing	❑	■*		❑	❑*	All Seismic Zones
2	Gable Bracing and Anchors	❑	■*		❑*	❑*	
3	Chimney Bracing	■*	❑	❑	❑	❑	
4	Appurtenances Attachment	❑	❑	❑	❑	❑	
5	Floor/Roof to Wall Anchors		■*	❑*	❑*	❑*	
6	Roof Mounted Equipment Attachment	❑*	❑*	❑*	❑*	❑*	
7	Shear Transfer Improvement	❑*	❑*	❑*	❑*	❑*	UBC Zones 2B, 3, 4 NEHRP A, ≥ 0.2
8	Strapping at Diaphragm Openings	❑*	❑*	❑*			
9	Drag Struts at Re-entrant Corners	❑*	❑*	❑*			
10	Plywood Diaphragm Stiffening/Strengthening	❑*	■*	■*			
11	Improving Chord Capacity	❑*	❑*	❑*			

Legend:

■ - Retrofit likely to be necessary

❑ - Retrofit may be necessary

* - Engineering design may be required

B. Exterior Walls Maintenance and and Repair/Window Replacement

Masonry Repointing
Window Replacement and Energy Conservation Improvements

Measure No.	Retrofit Measure	Building Type: Wood Frame	Unreinforced Masonry	Reinforced Masonry	Steel Frame	Concrete Frame	Applicability
5	Floor/Roof to Wall Anchoring		■ *	❑ *	❑ *	❑ *	All Seismic Zones
12	Adding Shear Capacity - Masonry Walls		❑ *	❑ *	❑ *	❑ *	
14	New Foundation Construction	❑					
15	Masonry Veneer Attachment	❑	❑		❑	❑	UBC Zones 2B, 3, 4 NEHRP A, ≥ 0.2
16	Cavity Wall Tie Improvement		❑ *	❑ *	❑ *	❑ *	
4	Appertenance Attachment	❑	❑	❑	❑	❑	
17	Improving Glazing Safety	❑	❑	❑	❑	❑	
11	Improving Chord Capacity	❑ *	❑ *	❑ *			

33

Legend:

■ - Retrofit likely to be necessary

❑ - Retrofit may be necessary

* - Engineering design may be required

C. Fire and Life Safety Improvements

Measure No.	Retrofit Measure / Building Type	Corridors, doors, stairs, entrances, sprinklers and alarms and accessibility improvements — Building Type: Wood Frame	Unreinforced Masonry	Reinforced Masonry	Steel Frame	Concrete Frame	Applicability
13	Strengthen Shear Walls with Plywood	❑*	❑*	❑*			All Seismic Zones
18	URM Wall Bracing		■*		❑*	❑*	
20	Attachment and Bracing of Ceilings, Lights and Equipment	■	■	■	■	■	
21	Attachment and Bracing of Cabinets and Furnishings	■	■	■	■	■	
19	Crosswall Extension		■*	❑*			UBC Zones 2B, 3, 4 NEHRP A, ≥0.2
7	Shear Transfer Improvements	❑*	❑*	❑*	❑*	❑*	

Legend:

■ - Retrofit likely to be necessary

❑ - Retrofit may be necessary

* - Engineering design may be required

D. Modernization/Remodeling/New Technology

Interior Remodel - Program Change
Air conditioning and Hazardous Materials Abatement

Measure No.	Retrofit Measure / Building Type	Wood Frame	Unreinforced Masonry	Reinforced Masonry	Steel Frame	Concrete Frame	Applicability
		Building Type					
5	Floor/Roof to Wall Anchors		■*	❑*	❑*	❑*	All Seismic Zones
13	Strengthening Shear Walls with Plywood	❑	❑*	❑*			
18	Unreinforced Masonry Wall Bracing		■*		❑*	❑*	
20	Attachment and Bracing of Ceilings, Lights and Equipment	❑	❑	❑	❑	❑	
21	Attachment and Bracing of Cabinets and Furnishings	❑	❑	❑	❑	❑	
17	Improving Glazing Safety	❑	❑	❑	❑	❑	
10	Plywood Diaphragm Stiffening/Strengthening	❑*	■*	■*			UBC Zones 2B, 3, 4 NEHRP A, ≥ 0.2
7	Shear Transfer Improvement	❑*	❑*	❑*	❑*	❑*	
9	Drag Struts at Re-entrant Corners	❑*	❑*	❑*			
11	Improving Chord Capacity	❑*	❑*	❑*			
19	Crosswall Extension		■*	❑*			

Legend:

■ - Retrofit likely to be necessary

❑ - Retrofit may be necessary

* - Engineering design may be required

E. Underfloor and Basement Maintenance and Repair

Foundation Repair - Underfloor Piping Work
Termite Repair - Underfloor Asbestos Removal

Measure No.	Retrofit Measure	Building Type					Applicability
		Wood Frame	Unreinforced Masonry	Reinforced Masonry	Steel Frame	Concrete Frame	
22	Bracing Cripple Stud Walls	■					All Seismic Zones
23	Installing Foundation Anchors	■ *					
24	Deterioration Repair/Replacement	❑					
14	New Foundation Construction	❑					
5	Floor to Wall Anchoring		❑ *				UBC Zones 2B, 3, 4 NEHRP A, ≥ 0.2

Legend:

■ - Retrofit likely to be necessary

❑ - Retrofit may be necessary

* - Engineering design may be required

V. Retrofit Measures

This section contains each of the suggested retrofit measures. Each retrofit measure is organized as follows:

- The number and name of the measure is shown. This coordinates with the matrices.
- The benefits of the measure in reducing seismic risk are noted plus other benefits or hazards.
- The benefits of combining the measure with specific maintenance and capital improvement activities are described.
- Outline statement of work, briefly describing the activity, is included. If engineering design is required or desirable, it is noted in the matrices.
- Priority factors for phasing the work are presented.
- Cost information is provided where available.
- If possible, photos of the measure in place are shown.
- Construction details taken from project drawings or the *FEMA-172 Handbook for Seismic Rehabilitation of Existing Buildings* are included when available.

Measure 1 - Parapet Bracing

Benefits of measure in reducing risk

Masonry parapets extending above the roof rock during an earthquake, and often they are the first elements to fall. Typically, the major parapets are located over exits and on the main facade of the building. It is not unusual to have parapets on all facades of schools. Parapet bracing is designed to eliminate this risk.

Bracing parapets for earthquakes also reduces the chance of the parapets falling under high winds.

Benefits of combining the measure with specific maintenance and capital improvement activities

Since parapet bracing involves some patching where the bracing is connected to the roof, the costs for roof patching may be reduced by combining this work with any other roof repair or replacement. In addition, the necessary specialty contractor (i.e., the roofer) is on the job, and access to the roof is easier since equipment will be at the job site.

Outline Statement of Work

Work includes bracing of masonry parapets with steel angles bolted to the parapet. The angles extend to the roof at a 30 to 45 degree angle. The angles are attached to a piece of angle that is connected to the roof. The roof may be wood, metal, or concrete. The relationship of the parapet's height to its thickness should not exceed a specific ratio determined by the seismic zone. If it does exceed this ratio, the parapet must be braced.

Priorities

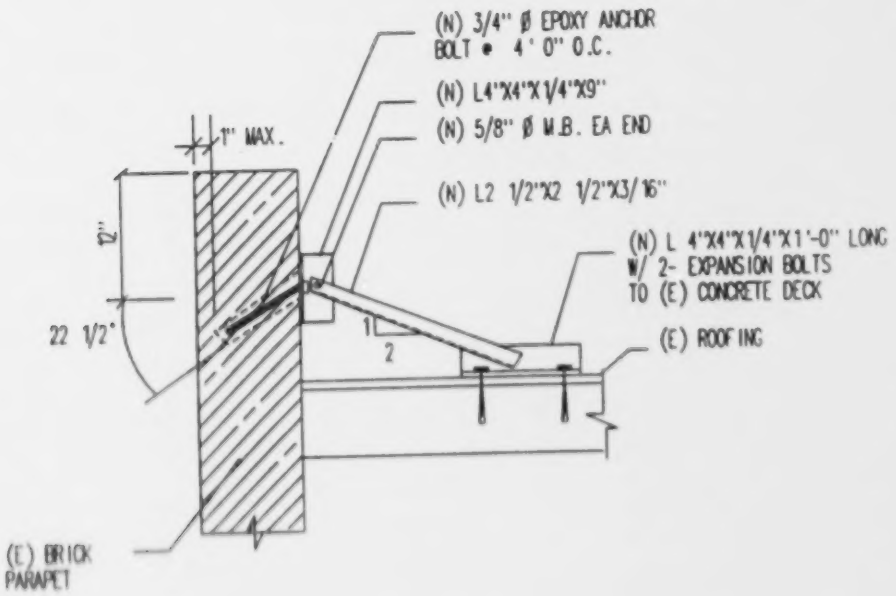
It is most desirable to brace all parapets that exceed the height to thickness criteria. If work has be to be constructed in phases, a suggested phasing from most to least hazardous is:

- Parapets over building exitways;
- Parapets over normally accessible areas such as walks, lawn areas, driveways, and streets;
- Parapets over areas such as planting areas that are unlikely to be occupied; and
- All other parapets

Details

See the discussion on engineering design when reviewing these details.

See illustration



PARAPET BRACING DETAIL

Measure 2 - Gable Bracing and Anchorage

Benefits of measure in reducing risk

Gables are much like parapets (See Measure 1 - Parapet Bracing). While gables appear to be attached to the roof, most are actually free standing and will rock during an earthquake. In many earthquakes, gables (along with parapets) are the first elements to fall. Gables are frequently located over exits. They may be on the main facade of the building as well as secondary facades. Gable bracing and anchorage is designed to eliminate the risks associated with earthquakes.

In addition, there will be improvement in the wind resistance of the gables when braced for earthquakes.

Benefits of combining the measure with specific maintenance and capital improvement activities

Gable bracing involves work on the inside of the gable usually in the attic. It involves attachments to the roof and wall. The work can be done at any time since it does not usually require any removal of finishes. It may be convenient to accomplish this when other work is done in the attic; however, it can be a stand-along task.

Outline Statement of Work

Work involves bracing of masonry gables. Work includes anchor bolts at the perimeters of the masonry connecting to the roof and ceiling; wood or steel vertical or horizontal braces inside the gable; and miscellaneous attachments. (See Measure 5 - Roof and Wall Anchoring.)

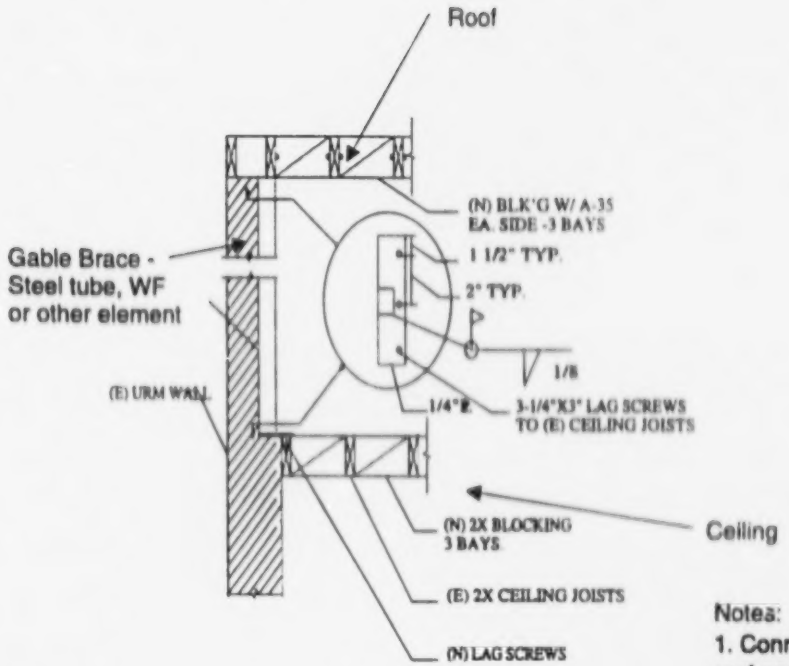
Priorities

Major gables are often constructed over building entrances. Phasing recommendations from most to least hazardous are:

- Gables over building exitways,
- Gables over play yards and public areas, and
- Gables over streets and drives

Details

See illustration.



Masonry Gable Bracing Detail

Notes:

1. Connection of brace to the roof and ceiling must be designed to resist calculated loads.
2. Brace must be connected to the gable with either through bolts or epoxy anchors.
3. Brace may be steel shape or wood depending on local codes.

Measure 3 - Chimney Bracing

Benefits of measure in reducing risk

Chimneys can pose a danger to persons outside the building. Chimneys can also pose a danger to occupants of the building if the chimney falls through the roof. Chimney bracing is designed to eliminate these risks.

In addition, seismic bracing should add strength to a chimney under high wind conditions.

Benefits of combining the measure with specific maintenance and capital improvement activities

Since chimney bracing connections are often made to the roof, there is an economy of combining this work with other roof work. (See Measure 1 - Parapet Bracing.)

Outline Statement of Work

Brace chimneys against toppling by installation of steel angle iron or rod bracing.

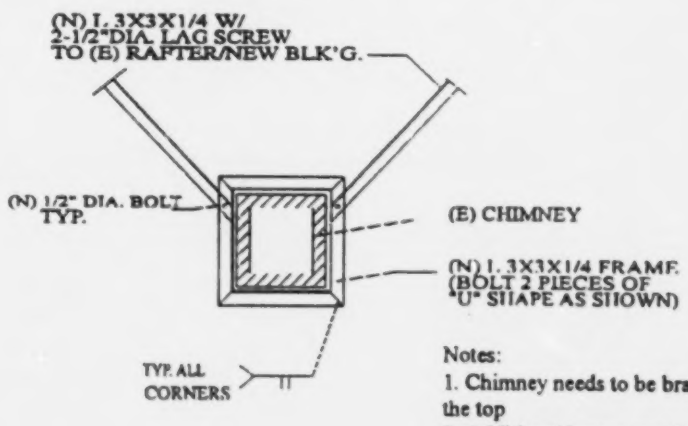
Priorities

Priorities for chimney bracing should be as follows:

- Chimneys above or adjacent to exitways, and high occupancy areas, either interior or exterior spaces;
- Chimneys above or adjacent to public yards, and
- All other chimneys.

Details

See illustration.



Notes:
1. Chimney needs to be braced near the top
2. Additional braces may be necessary depending on the chimney height.
3. Alternate designs may be necessary depending on structural and architectural conditions.

Chimney Bracing Detail

Measure 4 - Appurtenance Attachment

Benefits of measure in reducing risk

Falling ornamentation may kill or injure people adjacent to walls. Usually ornamentation is placed near principal entrances to a building, over or adjacent to the exit path.

Work undertaken for seismic reattachment will reduce the chance of appurtenances falling due to deterioration and wind.

Benefits of combining the measure with specific maintenance and capital improvement activities

Attachment of exterior ornamentation may be cost effective if combined with rerouting, repointing, or other masonry work where scaffolding is in place providing access to the work areas.

Outline Statement of Work

Physically attach ornamental elements and other appurtenances with anchor bolts or other connectors. (See Measure 1 - Parapet Bracing.)

Priorities

Ornamentation and appurtenances adjacent to exits should be checked and reanchored first, if necessary. Those over non-occupied areas can be completed next.

Details

Each design is specific for the element. The parapet and gable brace examples provide conceptual approaches to appurtenance attachment.

Measure 5 - Floor/Roof to Wall Anchoring

Benefits of measure in reducing risk

After parapet and gable failures, wall collapse is the next greatest hazard in earthquakes. Walls fall outward, creating a life hazard. This is called out-of-plane or tension failure. Further, the building's roof and floors may lose the support of the wall and collapse. Floor/roof to wall anchoring is designed to eliminate these risks.

Benefits of combining the measure with specific maintenance and capital improvement activities

If roof maintenance and repairs are planned, anchoring of walls to the roof can be undertaken at the same time. The cost of roof patching will be reduced and the necessary specialty contractor (i.e., the roofer) and equipment will be on the job site.

Wall to floor anchoring may be done when doing exterior wall or remodeling involving exterior spaces.

If parapet or gable bracing (measures #1 and #2) are undertaken, wall to roof anchors should be installed at the same time. These activities involve the same trades and occur in the same area of the building.

Outline Statement of Work

Work includes installing anchors through the wall and connecting them to the roof and floor diaphragms. The work may include fastening to the wood rafters of the roof and the floor joists. This will require patching of the roof covering. This also works for floors and roofs of other materials such as concrete.

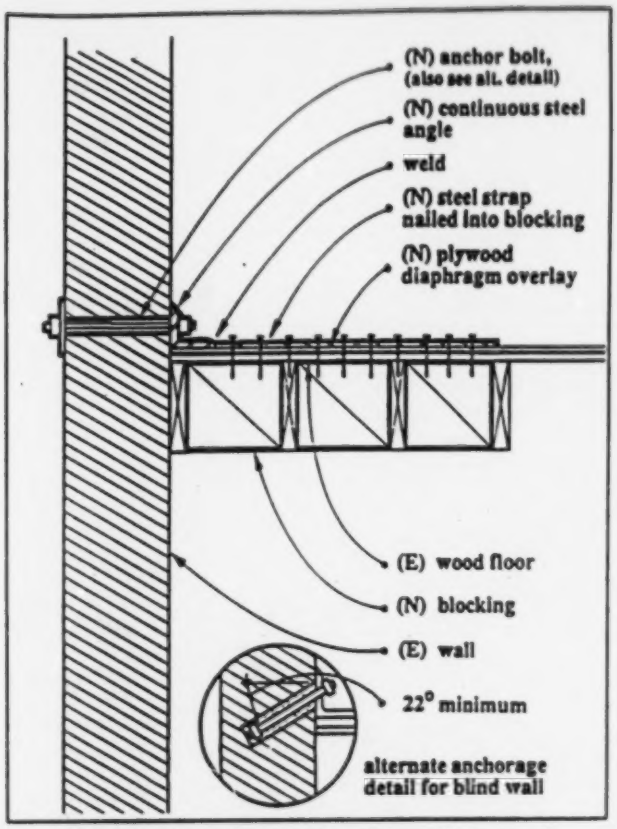
Anchors may be attached from the building interior, or from the underside of the roof or floor. This would include the bolt installation and blocking and strapping to the joists or rafters.

Priorities

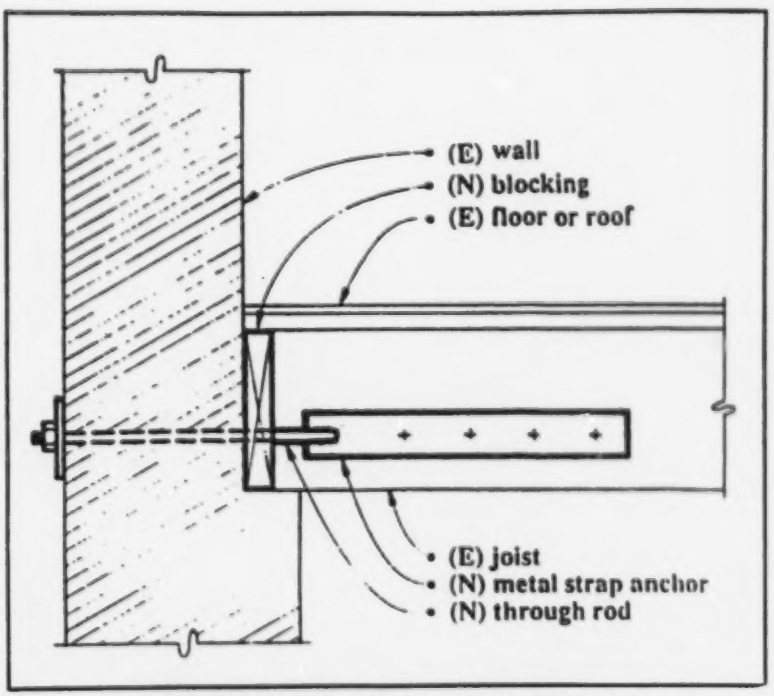
If phasing is required in multi-storied structures, first attach wall anchors at the roof line. Floors, starting at the top floor, should be a second phase. It is not necessary to anchor the first floor if the floor is less than three feet above grade.

Details

See illustrations



Example of a wall anchor to resist out-of-plane wall loads. Rafters/joists parallel to wall.



Example of a wall anchor to resist out-of-plane wall loads. Rafters/joists perpendicular to wall.

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Measure 6 - Roof Mounted Equipment Attachment

Benefits of measure in reducing risk

Equipment slides or topples during an earthquake. Attachment keeps it in place, reducing damage and down time.

Benefits of combining the measure with specific maintenance and capital improvement activities

When accomplished with roof work, the necessary attachments can be installed and waterproofed at the most effective time. Obviously, new roof mounted equipment should be installed with the appropriate anchors.

Outline Statement of Work

Provide a physical connection between roof mounted equipment such as A/C units and vent fans and the roof itself. Similar work may be accomplished for equipment in an equipment room.

Priorities

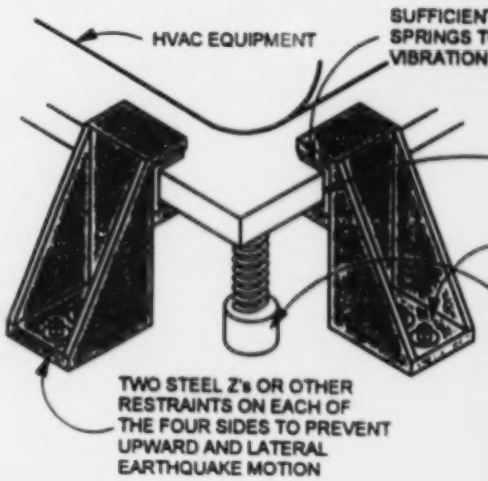
Equipment that is necessary for building function should be anchored first. Examples may be heating and ventilating equipment. Kitchen equipment and laboratory vents are secondary.

Details

This is an example solution. There are a number of products on the market that can provide seismic attachment for equipment.

See illustration

Retrofit restraint for mechanical equipment to limit lateral movement.


HVAC EQUIPMENT
SUFFICIENT GAPS TO ALLOW SPRINGS TO ISOLATE EQUIPMENT VIBRATION UNDER NORMAL USE
NEOPRENE "BUMPER" PADS
ANCHOR BOLTS
SPRING MOUNT (CHECK WITH VENDOR FOR SEISMIC MODEL)
TWO STEEL Z's OR OTHER RESTRAINTS ON EACH OF THE FOUR SIDES TO PREVENT UPWARD AND LATERAL EARTHQUAKE MOTION
NOTE: SPECIAL CARE SHOULD BE EXERCISED DURING DESIGN AS MANY RECENT FAILURES HAVE BEEN OBSERVED.

Measure 7 - Shear Transfer Improvement

Benefits of measure in reducing risk

Shear transfer distributes the earthquake (and wind) load through the building walls to the foundations. The shear is distributed to the wall by the diaphragm. The connection of the diaphragm to the wall must also be constructed so the shear forces are transferred into the lateral force resisting system. Improvements in shear transfer permits the forces to be distributed within a wall's capacity to resist loads. When properly done, this will reduce cracking and building damage.

Benefits of combining the measure with specific maintenance and capital improvement activities

Shear transfer improvement will require removal of finishes at the ceiling or roof line. When any interior improvements are made, such as ceiling replacement or asbestos abatement, work can be done to the wall and horizontal element connection. This may be effectively combined with the wall anchors (Measure 5) or shear wall improvements (Measure 12).

Outline Statement of Work

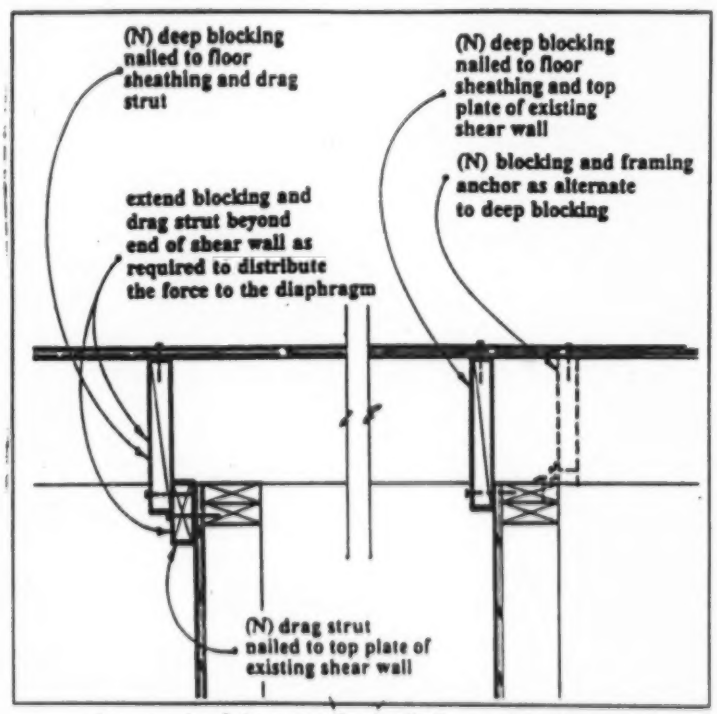
Work includes installation of metal and/or wood connectors to attach the roof or floor to walls. These may be interior or exterior walls. Spacing should be determined by engineering analysis.

Priorities

Not applicable.

Details

See illustration


(N) deep blocking nailed to floor sheathing and drag strut
(N) deep blocking nailed to floor sheathing and top plate of existing shear wall
(N) blocking and framing anchor as alternate to deep blocking
extend blocking and drag strut beyond end of shear wall as required to distribute the force to the diaphragm
(N) drag strut nailed to top plate of existing shear wall

An example of shear transfer details for wood buildings.

Measure 8 - Strapping at Diaphragm Openings

Benefits of measure in reducing risk

Diaphragms are weaker in terms of shear capacity where major openings occur. Examples include skylights, elevator shafts, and duct openings. Strapping improves diaphragm behavior by conveying the load around the opening.

Benefits of combining the measure with specific maintenance and capital improvement activities

Diaphragm strapping is best combined with other major roof work such as reroofing. It is also possible to accomplish this when major roof mounted equipment is being added or replaced.

Outline Statement of Work

Strapping at diaphragm openings is usually applied to a wood or light steel roof or floor. It involves installing steel straps around the perimeter of the opening. The straps will extend beyond the limits of the opening for varying lengths depending on the design loads in the diaphragm. The straps are nailed to wood roof framing and steel angles are typically bolted or welded to the deck and framing.

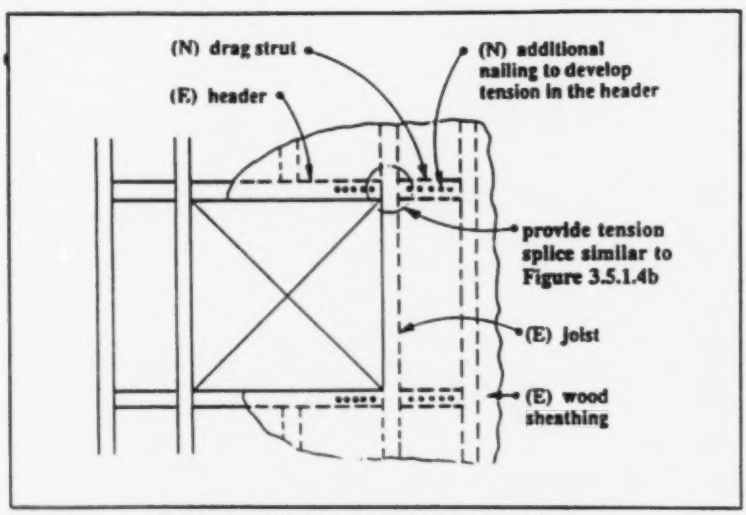
Priorities

It is lower in priority than the preceding measures (1-7). Engineering design is necessary to develop the most efficient system.

Details

This is a representative example. The exact solution will depend on the specific building construction.

See illustration


(N) drag strut
(N) additional nailing to develop tension in the header
(E) header
provide tension splice similar to Figure 3.5.1.4b
(E) joist
(E) wood sheathing

Reinforcement of an opening in an existing timber diaphragm

Measure 9 - Drag Struts at Re-entrant Corners

Benefits of measure in reducing risk

Buildings may crack or come apart at re-entrant corners. Drag struts, when properly designed and installed, will distribute the lateral forces through the building effectively.

Benefits of combining the measure with specific maintenance and capital improvement activities

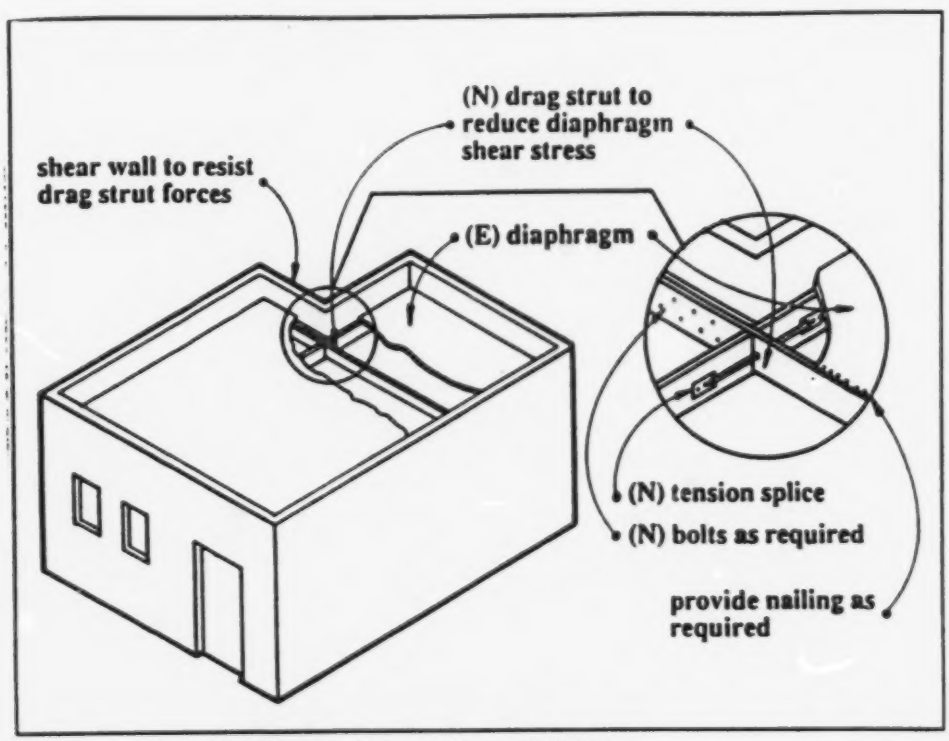
Strut installation can be combined with a number of maintenance items including reroofing and flooring replacement. It may also be done from under a floor and could be part of the work when asbestos abatement or ceiling work is undertaken.

Outline Statement of Work

Installation of steel straps and, if necessary, wood blocking at the roof and floors at re-entrant corners. These are typically at the corner of an "L, H, T, or U" shaped structure. Specific engineering design is necessary to assure the adequacy of the collector and drag elements.

Details

See illustration


(N) drag strut to reduce diaphragm shear stress
shear wall to resist drag strut forces
(E) diaphragm
(N) tension splice
(N) bolts as required
provide nailing as required

New drag strut in an existing wood diaphragm

Measure 10 - Plywood Diaphragm Stiffening/Strengthening

Benefits of measure in reducing risk

Plywood strengthens the roof for lateral loads and reduces damage potential. It is applicable to structures with wood roof or floors only.

Benefits of combining the measure with specific maintenance and capital improvement activities

This task can be accomplished when a reroofing operation and/or when remodeling involving access to flooring is underway. Costs will be reduced since there is equipment on the site for access and lifting materials, the contractor is already mobilized on the site, and the removal costs are combined in two work items.

Outline Statement of Work

The work involves installing plywood over existing roof sheathing. For floor stiffening, it is often applied over existing floor sheathing.

Priorities

Not applicable

Details

None

Measure 11 - Improving Chord Capacity

Outline Statement of Work

The chord is a perimeter element around the boundary of the roof or floor diaphragm. It may be wood, steel, or other type of member depending on the construction. The chord is installed to the roof and wall.

Benefits of measure in reducing risk

This measure will reduce the deflection of the diaphragm and result in reduced damage.

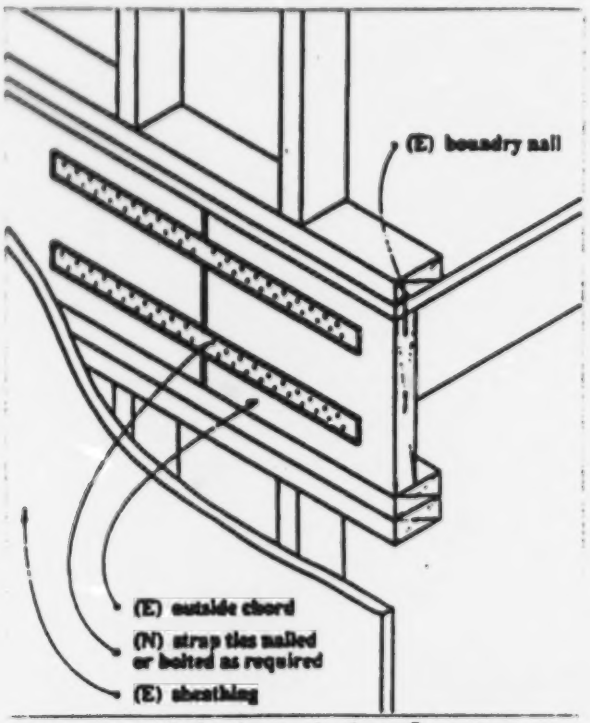
Benefits of combining the measure with specific maintenance and capital improvement activities

This can be installed at the time other roof work is underway. It may be installed at floor level when interior modernization or ceiling work is undertaken.

Details

This is an example detail. Several others are possible depending on the building.

See illustration



Example detail of perimeter chord retrofit measures.

Measure 12 - Adding Shear Capacity - Masonry Walls

Benefits of measure in reducing risk

Adding shear capacity improves the capacity of the wall to resist in-plane forces, i.e. parallel to the wall. Thir strength increase reduces the frequently observed diagonal wall cracking between openings and reduces the rocking of masonry piers at window and door openings.

Benefits of combining the measure with specific maintenance and capital improvement activities

This measure may be effectively applied when other interior or exterior work is underway. Window replacement, interior alterations, and exterior wall repointing provide opportunities to accomplish this measure.

Outline Statement of Work

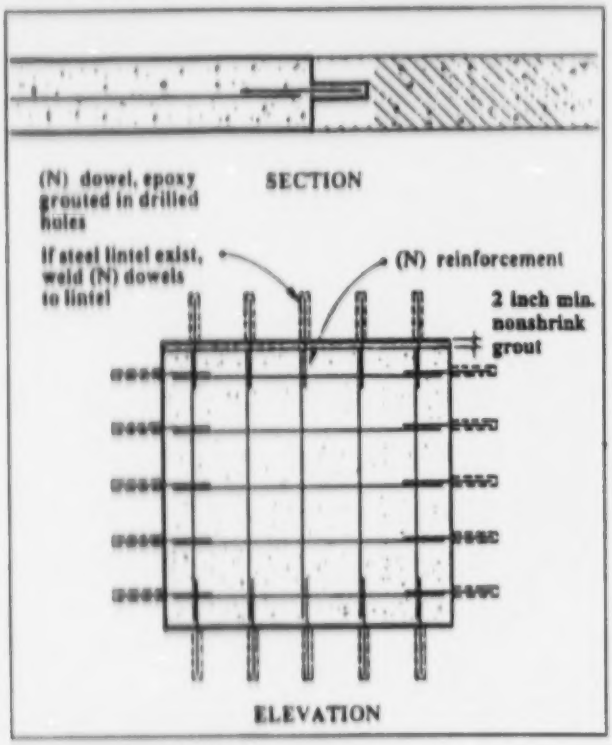
Bracing elements are often inserted into existing openings. Sometimes windows are partially or fully blocked in with masonry. In other cases, other materials may serve to strengthen masonry walls. This is typically shotcrete. Another option may be steel diagonal braces. Engineering design is necessary to assure compatibility of materials and stiffness.

Priorities

Not applicable

Details

See illustration


(N) dowel, epoxy grouted in drilled holes
SECTION
If steel lintel exist, weld (N) dowels to lintel
(N) reinforcement
2 inch min. nonshrink grout
ELEVATION

Example of details for enclosing an existing opening in a reinforced concrete or masonry wall.

Measure 13 - Strengthening Shear Walls with Plywood

Benefits of measure in reducing risk

This item, when combined with Measure 7 - Shear Transfer Improvement, will distribute the lateral loads through the walls of the structure.

Benefits of combining the measure with specific maintenance and capital improvement activities

When major interior work or fire safety improvements are undertaken, finishes are exposed or removed. At that time it is cost effective to install shear capacity improvements.

Outline Statement of Work

Plywood can be added to interior walls to improve their shear capacity. This involves the installation of plywood over studs. (Other options for shear improvements include masonry or concrete walls or steel frames.) Each will depend on the structure's needs.

Priorities

Not applicable

Details

None

Measure 14 - New Foundation Construction

Benefits of measure in reducing risk

Wood frame buildings have toppled off pier and post foundations. Installation of a new foundation will eliminate this type of risk.

Benefits of combining the measure with specific maintenance and capital improvement activities

When major subfloor work, such as termite or deterioration repair is underway, or other work on the exterior walls, this work can be accomplished at less cost.

Outline Statement of Work

Construction of continuous foundation walls under buildings on wood post and concrete pier footings. This involves supporting all or part of the building and construction of a new foundation, sill plate with anchor bolts, and tying the building to the new system.

Priorities

Not applicable

Details

None

Measure 15 - Masonry Veneer Attachment

Benefits of measure in reducing risk

Masonry veneer has fallen off walls of brick, wood frame, and other structural types as a result of earthquakes. It can also fall from other causes such as wind or deterioration. The veneer could kill or injure persons adjacent to the building. Veneer may be at entrances or yards. Seismic attachment of veneer will reduce potential risks due to deterioration or inadequate connectors.

Benefits of combining the measure with specific maintenance and capital improvement activities

This work can be effectively accomplished along with exterior wall maintenance tasks such as repointing or other seismic tasks such as floor/roof to wall anchoring (Measure 5), because access to the work is improved at that time.

Outline Statement of Work

Masonry veneer is brick or stone from 1/2 inch to 5 inches thick. This veneer will be found on buildings of masonry, wood, or other materials. It is attached to the structure with metal ties or wires. The tie spacing may be inadequate or non-existent in some cases. In other cases the ties may have corroded to a degree that there is no strength remaining.

To retrofit veneer anchors, steel pins or other devices are installed from the veneer to the substrate. This is done by drilling a hole through a masonry veneer unit or joint and into the substrate material. A steel pin is then epoxy anchored to the substrate and the veneer. Typically such veneer ties are placed in a pattern about 16 inches on center vertically and horizontally.

This method may be used to make up for deteriorated or missing ties. In that case the wall is checked using non-destructive tests, such as a pachometer, and the location missing a tie is noted. Then a new pin attachment is installed.

Priorities

Veneer retrofit should be phased in a manner similar to Measure 1 - Parapet Bracing, and Measure 2 - Gable Bracing and Anchoring.

Details

See Measure 16 - Cavity Wall Improvement for an example detail.

Measure 16 - Cavity Wall Improvement

Benefits of measure in reducing risk

The exterior wythe of a cavity wall may fall outward under earthquake loads if not sufficiently anchored, or if the anchors have deteriorated. Persons adjacent to such a wall are at risk. Cavity wall improvements are designed to reduce this risk.

Benefits of combining the measure with specific maintenance and capital improvement activities

This work can be effectively accomplished with several exterior wall maintenance tasks such as repointing. It may also be done with several seismic tasks such as floor/roof to wall anchoring (Measure 5). The effectiveness of combining this with the maintenance is that scaffolding and other access methods would be on the job at that time.

Outline Statement of Work

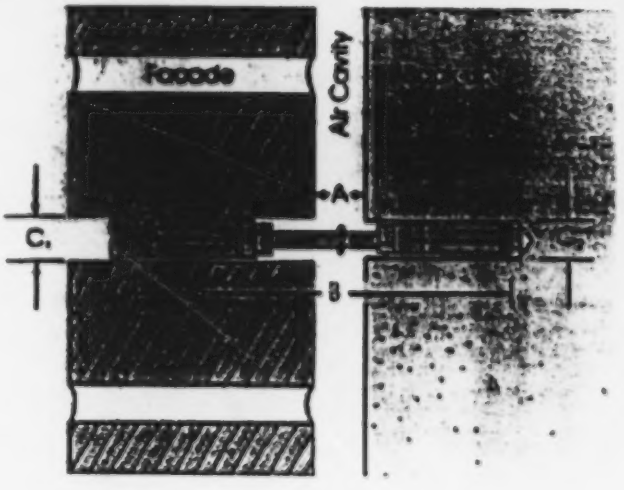
Cavity walls are of masonry construction. The inner wythe is typically the load bearing portion. The exterior wythe is spaced out from the inner wall about 2 inches and connected to the inner wythe with ties. This space is ventilated by openings near the base of the wall. Usually the head joints of alternate bricks along the base are left open.

Retrofit is accomplished by installing steel pins or other devices from the exterior wythe to the inner wythe. This may be done by drilling a hole through an exterior masonry unit or joint and into the inner wythe. A steel pin is then epoxy anchored to the inner and the exterior wythe. Typically such ties are placed in a pattern about 16 inches on center vertically and horizontally.

This method may be used to make up for deteriorated or missing ties. In that case the wall is checked using non-destructive tests, such as a pachometer, and the location missing a tie noted. Then a new pin attachment is installed.

Details

See illustration



An example of a retrofit device for cavity walls and masonry veneer.

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Measure 17 - Improving Glazing Safety

Benefits of measure in reducing risk

Glazing has cracked, broken, and fallen during earthquakes. Sometimes the glass shatters, explosively sending glass shards horizontally into the building. Large plate glass pieces have fallen to the ground. There is a chance that falling glazing could injure or kill persons adjacent to a window, on the interior or exterior. This improvement can also reduce the chance of accidental injury due to breakage.

Benefits of combining the measure with specific maintenance and capital improvement activities

This measure can be combined with other window or energy conservation activities which will result in some cost savings.

Outline Statement of Work

Work may include some or all of the following:

- Replacement of glazing with tempered or laminated glass
- Installation of new windows with smaller panes of glass
- Applying a coating over the glazing to reduce chances of broken pieces falling

Priorities

Details

None

Measure 18 - Unreinforced Masonry Wall Bracing

Benefits of measure in reducing risk

Many interior walls along corridors are of masonry construction (brick, block, hollow clay tile). This retrofit measure is intended to reduce the chance of a masonry corridor wall falling into the room or corridor during an earthquake.

Benefits of combining the measure with specific maintenance and capital improvement activities

This improvement can be done as part of any work in the attic, modernization, or fire safety improvements.

Outline Statement of Work

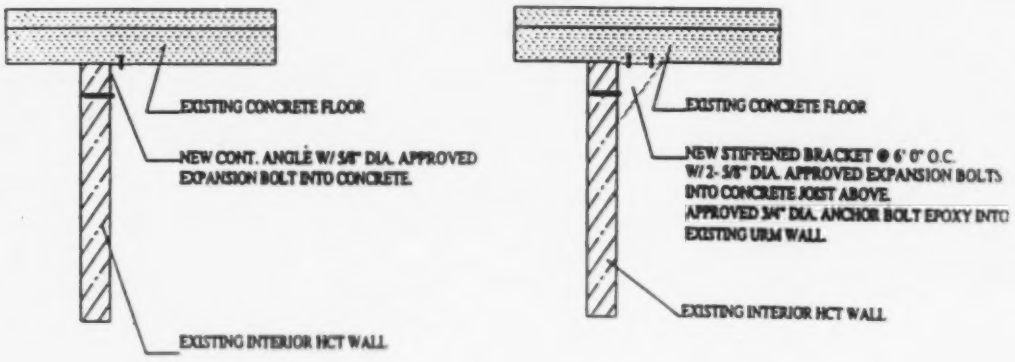
This task involves installation of bracing from the top of the wall to the structure above.

Priorities

Bracing masonry walls for out-of-plane movement is an important work item. Although considered "non-structural," it may effectively be included with other wall strengthening work.

Details

See illustration


EXISTING CONCRETE FLOOR
NEW CONT. ANGLE W/ 5/8" DIA. APPROVED EXPANSION BOLT INTO CONCRETE.
EXISTING INTERIOR HCT WALL
EXISTING CONCRETE FLOOR
NEW STIFFENED BRACKET @ 6' 0" O.C. W/ 2- 5/8" DIA. APPROVED EXPANSION BOLTS INTO CONCRETE JOIST ABOVE.
APPROVED 3/4" DIA. ANCHOR BOLT EPOXY INTO EXISTING URM WALL.
EXISTING INTERIOR HCT WALL

Example methods of bracing masonry walls for out-of-plane forces.

Measure 19 - Crosswall Extension

Benefits of measure in reducing risk

This retrofit measure uses interior stud walls to create a wall that can reduce deformation of the roof diaphragm in a masonry structure with wood roof. Cross wall installation can reduce the need for plywood sheathing on the roof in many cases.

Benefits of combining the measure with specific maintenance and capital improvement activities

Since this work is done in the attic, it can be combined with other work such as heating replacement, duct work changes, asbestos abatement, and fire safety improvement.

Outline Statement of Work

A wood stud and plywood shearwall is installed in the attic space between an existing stud wall and the roof or floor above. The wall is attached to the top of the stud wall and the roof diaphragm. This is applicable where the walls do not extend to the roof or floor.

Priorities

Details

None

Measure 20 - Attachment and Bracing of Ceilings, Lights, and Equipment

Benefits of measure in reducing risk

Suspended ceilings and lights have collapsed during small to moderate earthquakes. While ceiling tiles are lightweight, they pose some hazard to anyone that is struck by one. Light fixtures are heavy and if one fell and struck a person below, it could cause some significant injury or even death.

Mechanical equipment can fall or slide off supports. When this occurs it can break water or gas lines and be out of service. Broken water and gas lines are themselves a potential hazard.

Ductwork in the ceiling can collapse and fall into a room. Ceiling registers at the end of ducts can also fall and cause a hazard.

Automatic fire extinguishing systems may be needed after an earthquake. They may break from the shaking and flood the building.

Benefits of combining the measure with specific maintenance and capital improvement activities

Ceiling bracing can be installed at the time any ceiling work is underway. Lights may be hung at the time of installation, ceiling rework, or even as part of a general relamping activity.

Attachment of equipment can be accomplished when it is being replaced or when there is major service on a unit. If there is any work underway that may provide easy access to ducts, additional sway bracing or supports can be installed economically and easily.

Fire sprinkler systems can be upgraded for seismic loads during any ceiling, fire safety improvement, or interior alterations.

Outline Statement of Work

Suspended ceiling bracing consists of installing four sway wires from the ceiling support to the structure above at about 12 feet on center each way. A vertical strut is also installed at the point where the wires attach to the ceiling support channels.

Suspended light fixtures must be independently hung from the structure above. A minimum of two independent hangers is necessary. A similar method is used for duct registers.

Ductwork above a certain size requires sway bracing and supports back to the structure.

Equipment requires anchorage and sometimes bracing. Positive anchors to the structure will prevent sliding of mechanical and electrical equipment. Kitchen equipment should also be anchored.

Fire sprinkler systems require sway bracing from the pipe to the structure. The spacing of the bracing is a function of the size of the pipes. Current systems may require a brace every 400 square feet or more.

Priorities

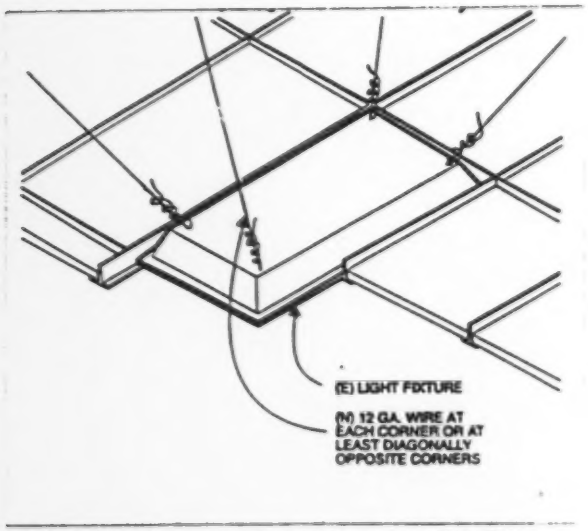
Priorities may depend on specific programs and planned activities. A suggested order of importance is:

- Pendant light fixtures
- Suspended ceilings\light fixture system
- Fire extinguishing systems
- Duct work
- Mechanical equipment important for continued building operations
- Kitchen equipment
- Other mechanical equipment

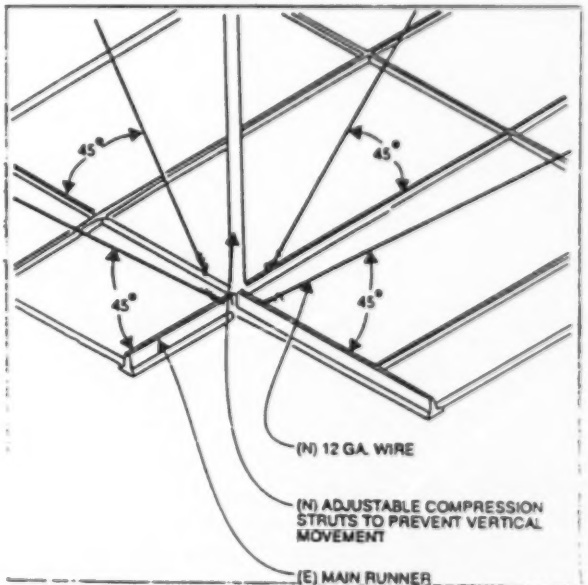
Details

The details are for attachment and bracing of suspended light fixtures and ceilings. Those on the next page are possible methods to use for pendant light fixtures and lightweight partitions.

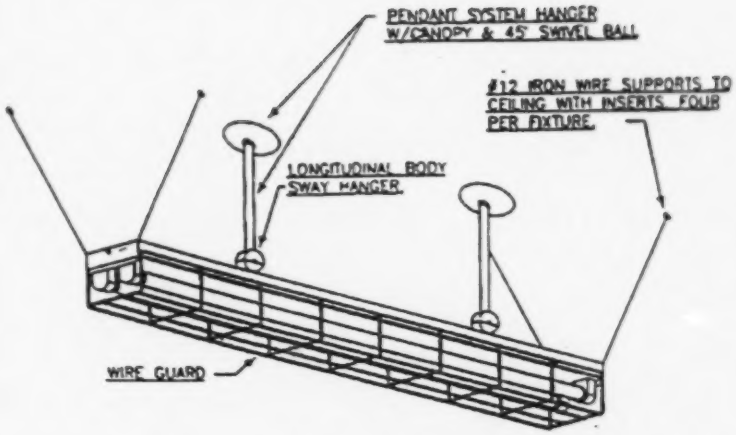
See illustrations



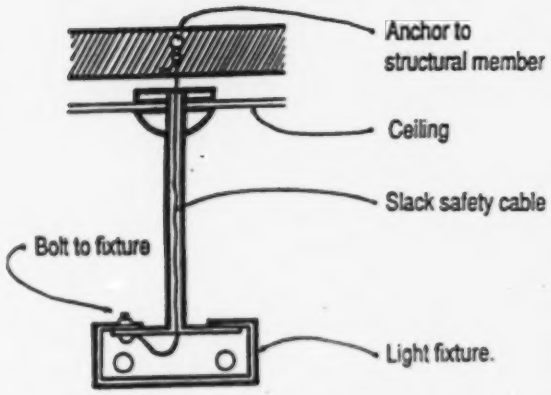
Independent wires are required to support light fixtures.



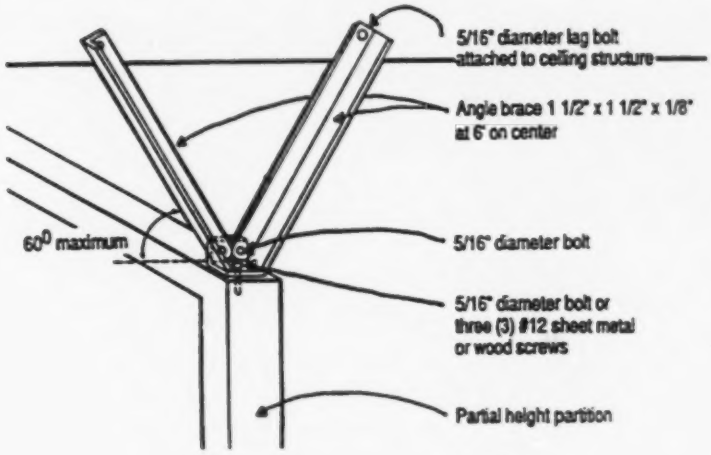
Diagonal wires are used to brace suspended ceilings.



Safety wire system for pendant light fixture. This method may be a cost effective approach.



Safety wire for pendant light fixture. This may not be a cost effective. The detail shown on the left may prove easier and less expensive to install.


5/16" diameter lag bolt
attached to ceiling structure
Angle brace 1 1/2" x 1 1/2" x 1/8"
at 6' on center
60° maximum
5/16" diameter bolt
5/16" diameter bolt or
three (3) #12 sheet metal
or wood screws
Partial height partition

Seismic bracing of nonstructural partitions and room dividers.

Measure 21 - Attachment and Bracing of Cabinets and Furnishings

Benefits of measure in reducing risks

Interior furnishing and equipment may shift and slide during an earthquake. They can block doors preventing exit or rescue. The cost for simply replacing library books on a shelf, or resorting records is high.

Benefits of combining the measure with specific maintenance and capital improvement activities.

While much of this work can be done at any time, it is more easily done when a space is being altered or new furnishings purchased.

Outline Statement of Work

The work varies depending on the individual item of equipment. A major goal is to prevent shelving and cabinets from overturning. Simple attachment to the wall may be all that is required. However, it is important to verify the stability of the wall that something is being connected to.

Attachment to frame walls must be to a stud and not simply to the wallboard or plaster.

Other furnishings will require attachment using ordinary screws, angles and other commercial products. The details will depend on the weight of the item, need for moving the item, and specific conditions.

Priorities

Details

None

Measure 22 - Bracing Cripple Stud Walls

Benefits of measure in reducing risk

Cripple studs are short wood studs below the first floor, in wood frame buildings. They are usually between the foundation wall and the first floor. These cripple studs have toppled, almost domino fashion, in earthquakes.

This measure will prevent cripple studs from toppling during an earthquake.

Benefits of combining the measure with specific maintenance and capital improvement activities

This retrofit measure should be accomplished with the installation of foundation (Measure 23) anchor bolts.

This may be combined effectively with other underfloor repairs or work.

Outline Statement of Work

Installing plywood sheets on the surface of cripple studs that are between the floor and foundation of wood frame buildings. The plywood is typically installed at each corner, approximately 8 feet in length in each direction. Plywood must have ventilation holes to prevent moisture accumulation and rotting of the studs.

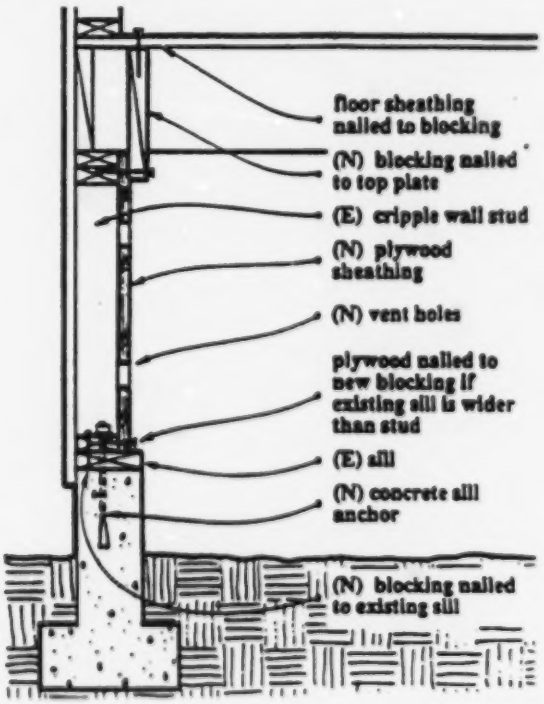
Priorities

Cripple stud bracing is important for simple wood buildings.

Details

See illustration

Plywood at corners is used to brace the cripple studs against overturning. Anchor bolts should be installed if necessary.


floor sheathing nailed to blocking
(N) blocking nailed to top plate
(E) cripple wall stud
(N) plywood sheathing
(N) vent holes
plywood nailed to new blocking if existing sill is wider than stud
(E) sill
(N) concrete sill anchor
(N) blocking nailed to existing sill

Measure 23 - Installing Foundation Anchors

Benefits of measure in reducing risk

Light wood frame buildings shift off their foundations because they are not properly attached to the foundation. This retrofit, installing anchor bolts, corrects this problem.

Benefits of combining the measure with specific maintenance and capital improvement activities

The work can be combined with other underfloor construction, plumbing, or heating work. This work should be accomplished in conjunction with cripple wall bracing (Measure 22).

Outline Statement of Work

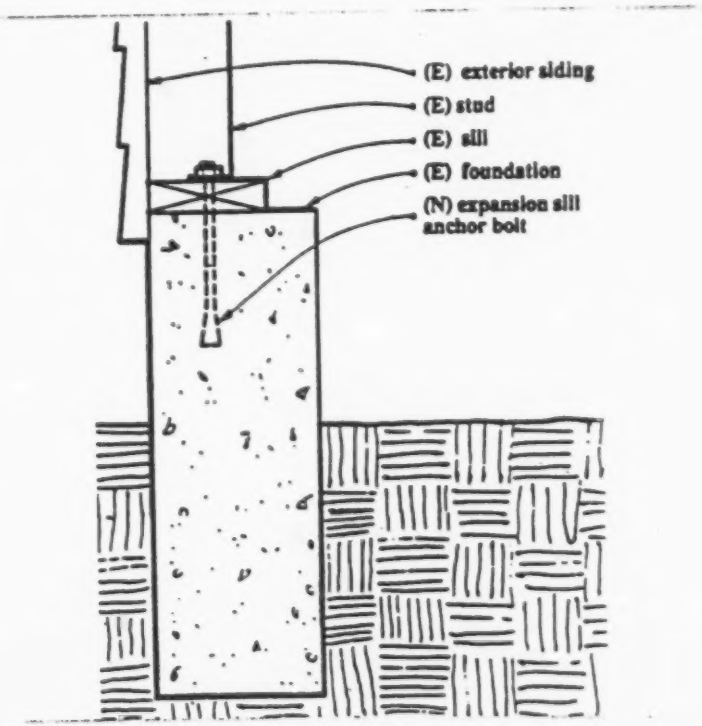
Installation of expansion bolts or other anchors from the building's sole plate to the foundation. There are a number of products now available for tight locations.

Priorities

Anchor bolts and cripple stud bracing should be done together if both measures are required.

Details

See illustration



Detail of anchor bolt installation. New Products are on the market to permit easier installation of bolts.

Measure 24 - Deterioration-Repair/Replacement

Benefits of measure in reducing risk

A number of general building maintenance items contribute to improved seismic performance. Recent earthquakes have shown the importance of masonry pointing as a contributor to the strength of walls. Eliminating "dry rot" in wood structures will assure the required strength is maintained.

Loss of support for foundations when the soil has eroded or settled has resulted in building damage. This frequently is associated with the building's drainage systems.

Benefits of combining the measure with specific maintenance and capital improvement activities

Combining repair of deteriorated components may be cost effective when combined with other building work.

Outline Statement of Work

None

Details

None

Appendix

Documents

Resource documents include the FEMA NEHRP Handbooks, local and state building codes and earthquake design books

References

References include the CSI and other model specifications, existing building plans and the building's maintenance history.

Specifications

Standard specifications should be prepared for use in obtaining bids for work. The CSI and AIA formats contain sections on rehabilitation of various materials. However special sections, usually revisions of other sections, may have to be prepared for epoxy anchored bolts and similar specialities.

Information Sources

There are a number of information sources noted in this report and available elsewhere. Publications by FEMA, engineering associations and commercial publisher will provide the necessary information.

Building codes should always be consulted for the appropriate design levels. Many states are now adopting seismic construction legislation that will affect schools.

Local suppliers and sources such as the Sweet's Catalogue are important sources of information.

Consultants

Architects and engineers specializing in existing buildings and seismic rehabilitation should be identified as potential consultants.

Contractors

Contractors who specialize in seismic rehabilitation of existing buildings can provide school districts with cost information for budget purposes as well as bid on projects.

Specialty contractors

Speciality contractors should be identified. Such contractors include those specializing in concrete and masonry rehabilitation, waterproofing and masonry retrofit.